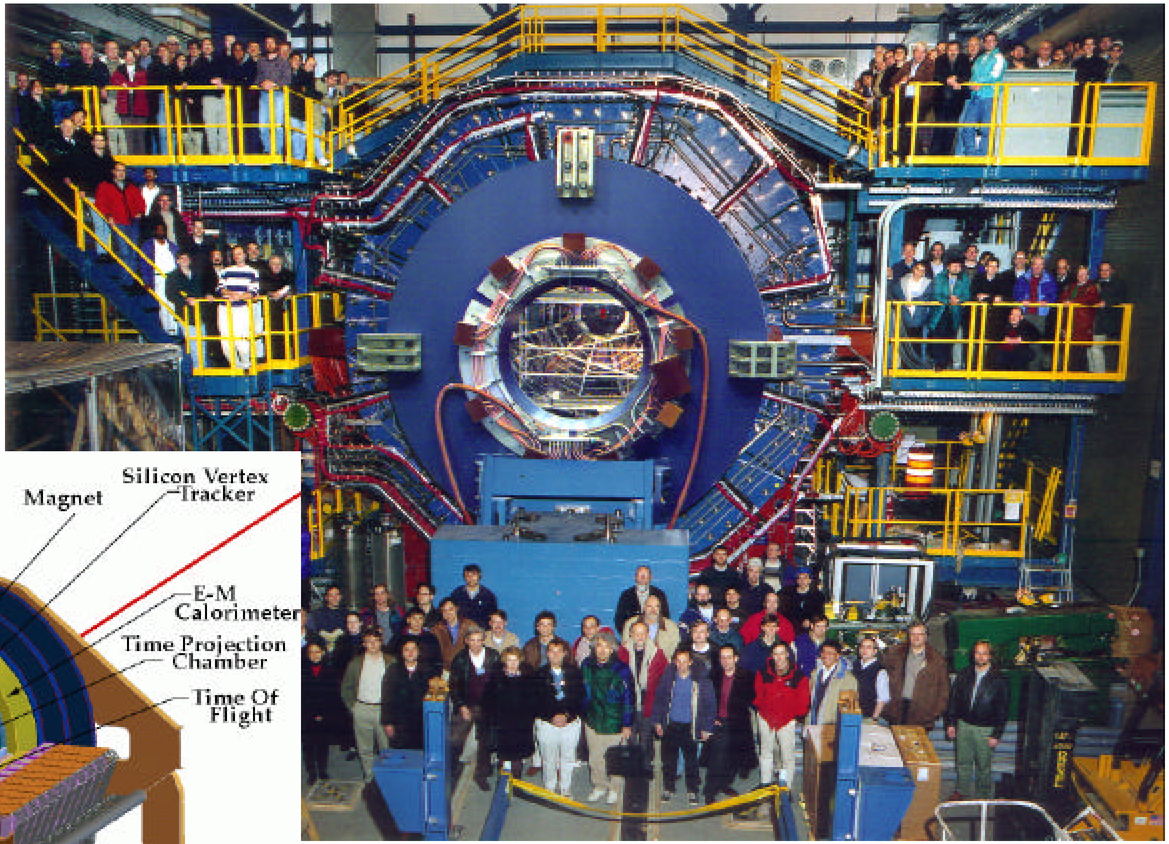
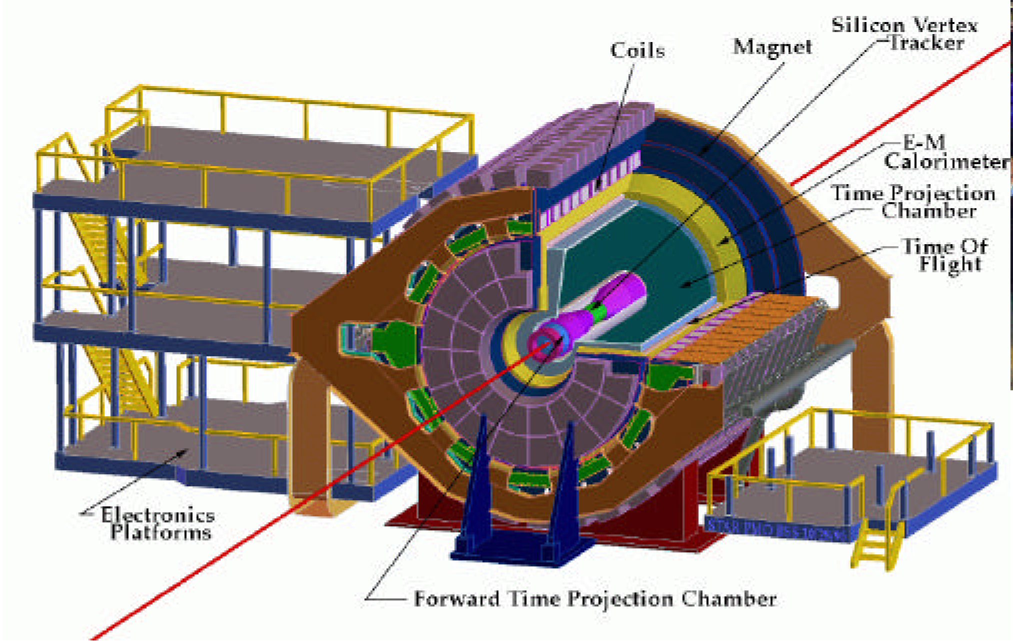
highPt @ RHIC

Gerd J. Kunde, Yale

- Definition
- Physics
- Observables





- Future
- Proposal

What do we want to understand ?

• highPt Quest is to understand how hard processes behave in a strongly interacting medium
• Study pQCD predictions

• Experimental access by measuring
– pp (baseline)
– eP (cold matter)
– pA (nuclear effects)
– AA (QGP ?)

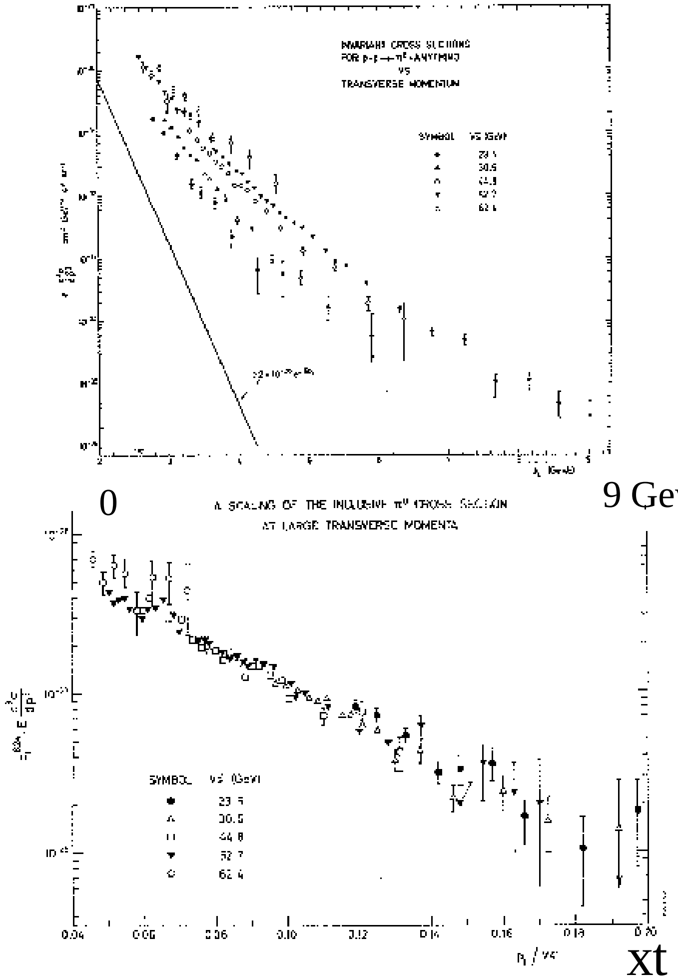
What means 'high' in highPt ?

- Hadron formation time:
  - Confinement scale R_h ~ 1/Lamba$_{QCD}$
  - In parton frame: k_{long} ~ k_{trans} ~ R_h
  - In lab with gamma = E_{jet}/m -> k_{long}=gamma*k_{long}
  - Formation time T of hadron is equals k_{long}/k^2_{trans}
    - light -> mass ~ R_h^{-1} T= $E_{jet}R_h^2$
    - heavy-> mass~ m_q T= $E_{jet}R^h/m_q$
  - Consider a 3 GeV hadron coming from a E_{Jet} ~ E_H
    - with Lamda$_{QCD}$ ~ 200 MeV gives $T_{formation}$ ~ 5-10 fm
  - That's outside the medium
  - 3 GeV Pions already fall into the region of 'moderate high' Pt
- Hijing approach: The hard cutoff p_0 = 2 GeV/c
- Theorist approach :-)
  - If we understand anything about QCD then highPt is where the anti-proton over proton ratio starts falling !!!!

What is the right scale P_{trans} or x_t?

F. W. Büsser, et al., Phys. Lett. **46B** 471 (1973)

- Already asked 1973 from ISR data
- Normalized Scale $x_t=2*P_t/Sqrt(s)$
- Data fit $\sim P_{trans}^{-8}*F(x_t)$

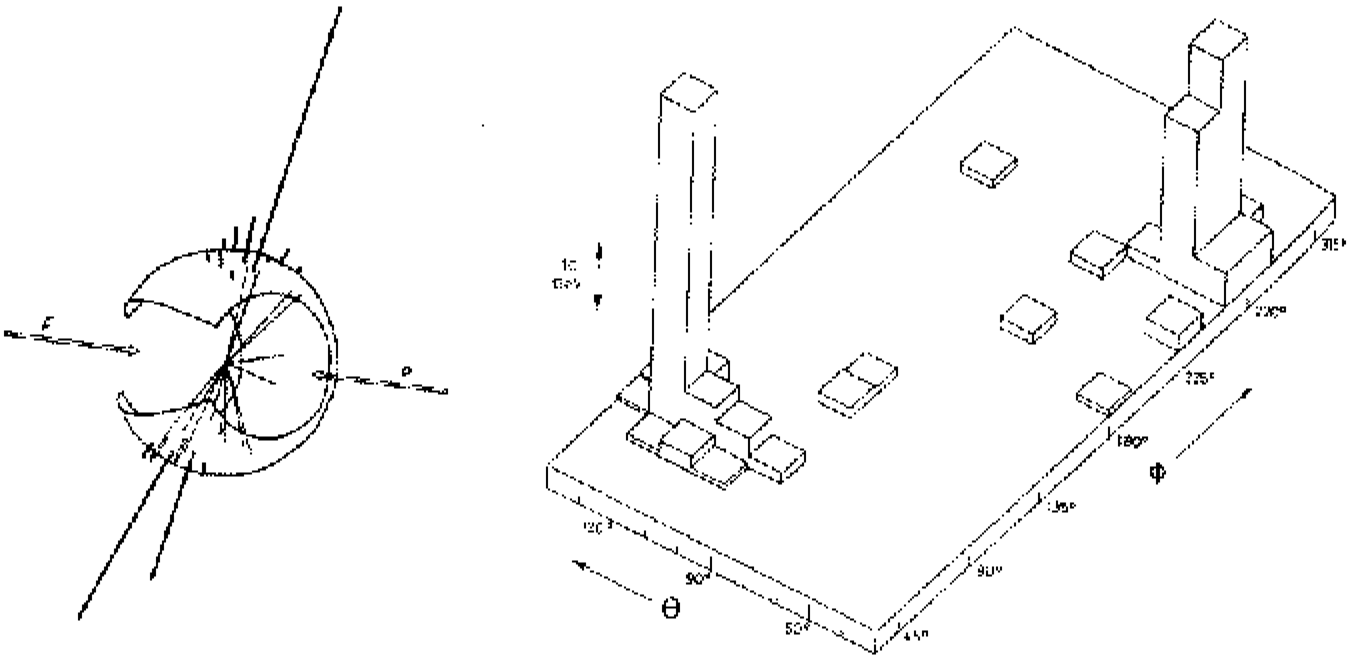


Data from 23.5 to 62.4 GeV

Figure 2: Top(t): CCR transverse momentum dependence of the invariant cross section at five center of mass energies. Bottom(b): The above data multiplied by $p_\perp^n$, using the best fit value of $n = 8.24 \pm 0.05$, with $F = Ae^{-bx_\perp}$, plotted vs $p_\perp/\sqrt{s}$.

Why we are here or Jets since 1982

Int'l HEP Conference, Paris, 1982
The UA2 Two-Jet Event



Can't see them directly in AA :

Taking Phenix Et data gives you ~300 GeV in cone

Jets in pA and AA

- Partonic energy loss dE/dx is sensitive to energy density
- dE/dx influences fragmentation function
- Initial state effects (shadowing and k_t)
- pp and pA comparison essential

Other highPt topics

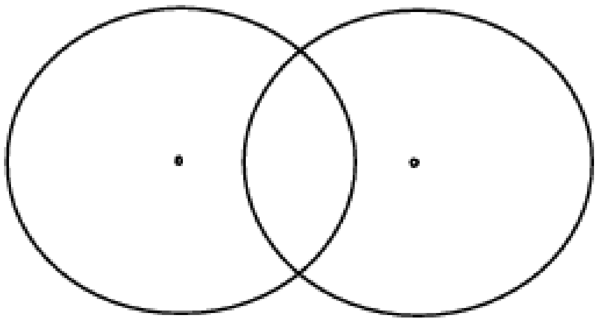
- Inclusive Hadron spectra
  - AA influenced by multiple scattering and flow
  - pA by multiple scattering and shadowing
- Multiple Scattering via Dijets in pA
  - measure acoplanarity as function of A
- Charm
  - Jpsi suppression and open charm
- Gluon Distribution in Nuclei
  - no only polarized but unpolarised

Nuclear Effects

- Next few slides on
  - Scaling between pp pA and AA
  - Kt and Cronin effect

The A+B - T_{AB} Scaling

- Assumes Hard-Scattering is a point-like process, therefore for p-A it should scale with A and for A-A is should scale with A2



$$T_A(\vec{s}) = \int dz \rho_A(z, \vec{s})$$

$$T_{AB}(\vec{b}) = \int d^2 s T_A(\vec{s}) T_B(\vec{b} - \vec{s})$$

$$T_{AB}(\vec{b}) = N_{coll}(\vec{b}, \sigma)/\sigma$$

$$\frac{1}{N_f} \frac{d^3 N_f^{A+A}}{p_T dp_T dy d\phi} = \frac{d^3 \sigma^{p-p}}{p_T dp_T dy d\phi} \times \langle T_{AB} \rangle_f \cong \frac{d^3 \sigma^{p-p}}{p_T dp_T dy d\phi} \times \frac{\langle N_{coll}(\sigma_{nn}) \rangle_f}{\sigma_{nn}}$$

Problems concerning TAA

- Number of binary collision only well defined for central AA collisions
  - Centrality dependence has large errors on T_{AA} for peripheral data
  - Important to measure different ‘A’s !!!!
- What to compare in experiments?
  - Central AA over scaled pp
  - Central AA over minbias AA (T_{AA} drops out)
  - Compare minbias AA and scaled pp

Kt Measurement by triggering on Leading Parton (ISR)

- Kt is not a 'fudge factor'
- It is the measurable broadening due the medium

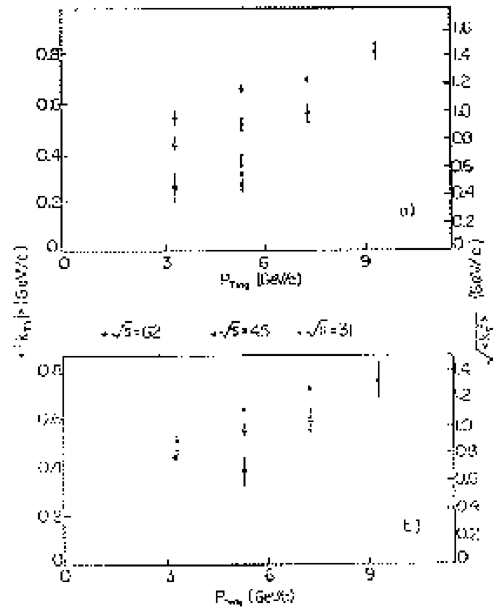
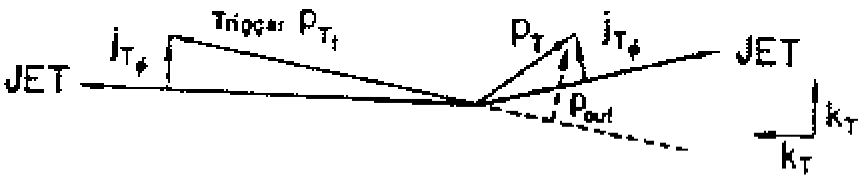


Figure 7: (a) $\langle|k_{Ty}|\rangle$ and $\sqrt{\langle\langle k_T^2\rangle\rangle}$ as a function of p_{Ttrig} for three different $\sqrt{s}$ values, obtained from back-back correlations. (b) The same using events where the sum of charged paricle transverse momenta on the away side balances p_{Ttrig} [see Phys Lett **97B** (1980) 163].

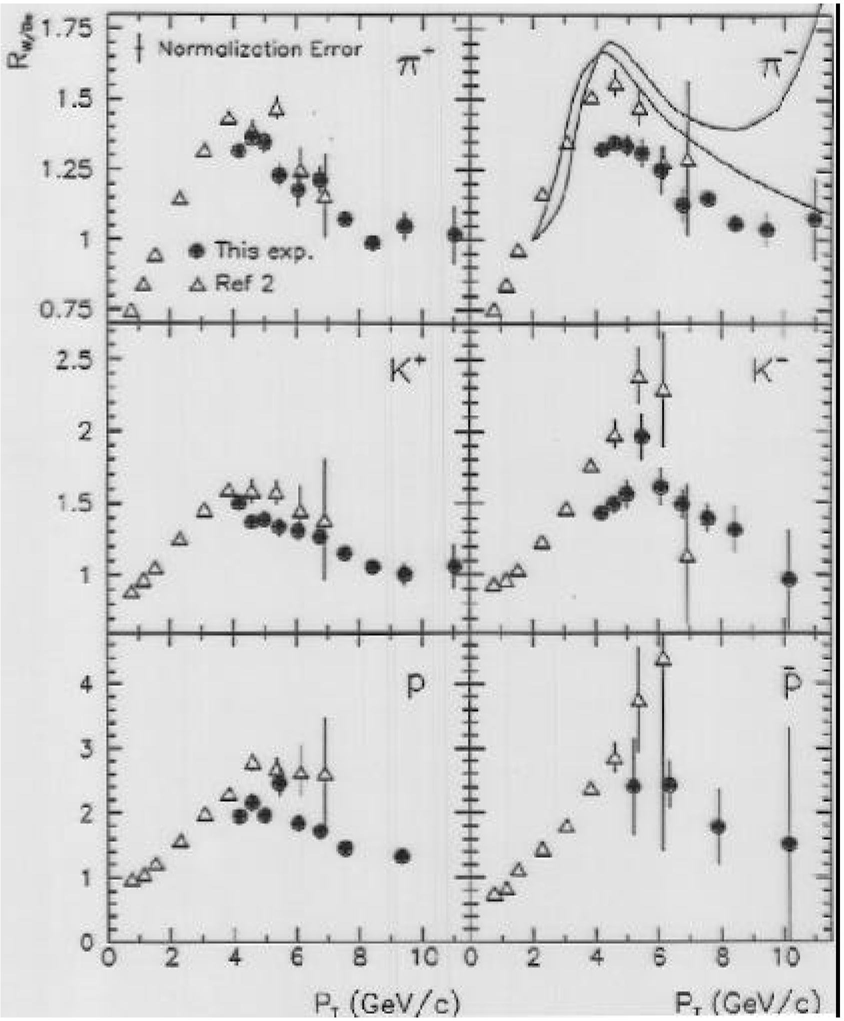


$$\langle|p_{\rm out}|\rangle^2 = \langle|j_{Ty}|\rangle^2 + \; x_E^2(\,\langle|j_{Ty}|\rangle^2 + 2\,\langle|k_{Ty}|\rangle^2\,)$$

Theorist try to interpret the value

Cronin Effect at FNAL Sqrt(s) = 38.8 GeV Ratio(W/Be)

- Measurement of the particle dependent Cronin effect
- Depends on the Species
- Highly desirable measurement in STAR

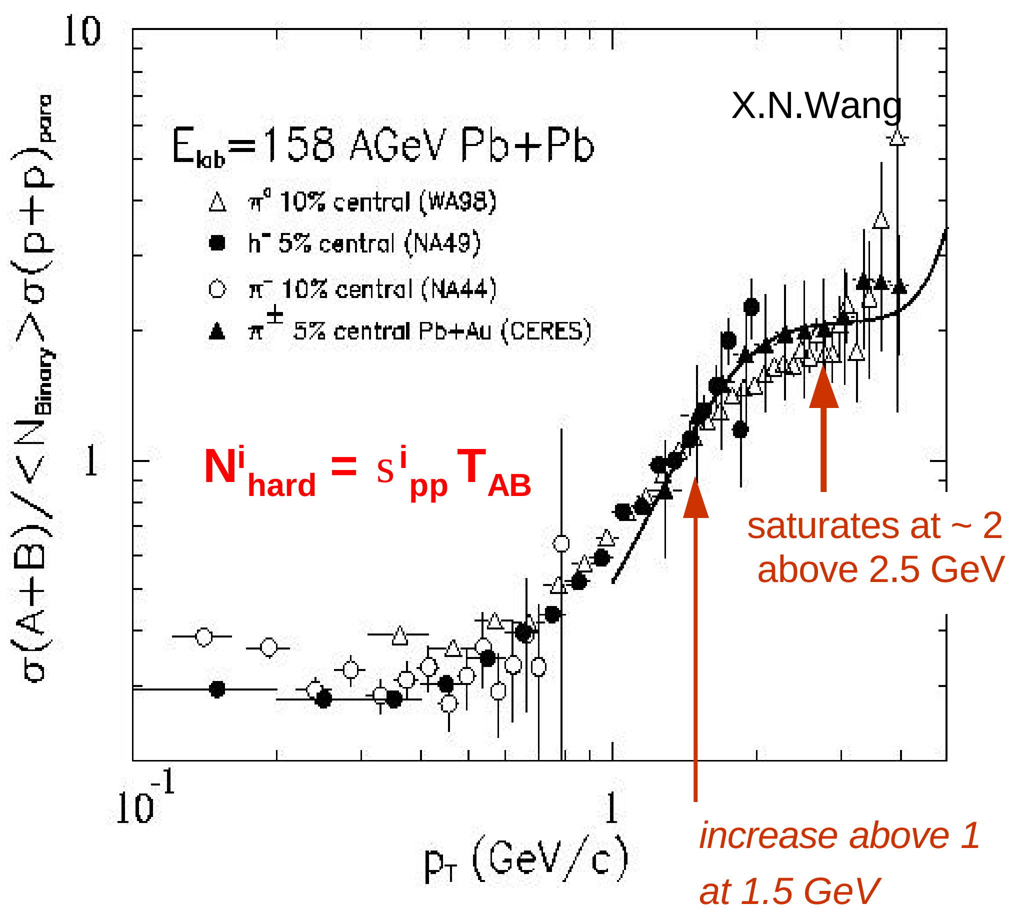


Comparing AA to pp: Results from the SPS

hard scattering processes scale with binary collisions:

$$\langle N_{binary}\rangle = \sigma_{pp}^{inel}\frac{\int_0^{b_c} db^2 T_{AA}(b)}{\int_0^{b_c} db^2} = \sigma_{pp}^{inel}\frac{\int_0^{b_c} db^2 T_{AA}(b)}{f\,\sigma_{AA}^{inel}} = \sigma_{pp}^{inel}\langle T_{AA}\rangle$$

$\langle N_{binary}\rangle = 1092 \leftrightarrow \langle T_{AA}\rangle = 26\ mb^{-1}$

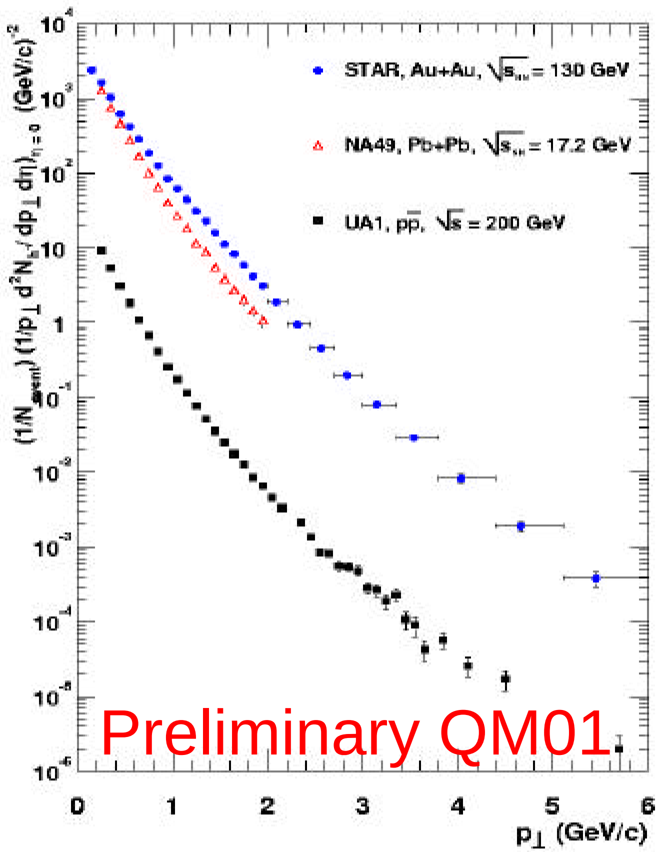


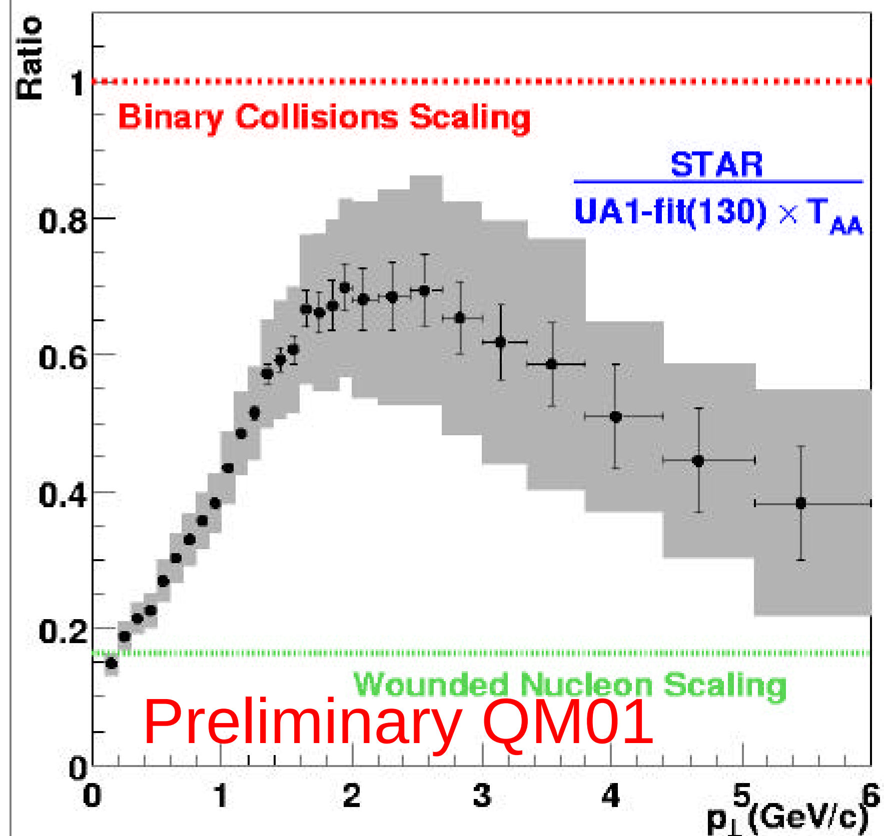
Nuclear Modification Factor:

$$R_{AB} = \frac{1}{\langle N_{binary}\rangle}\left(\frac{d^2\sigma_{AB}}{dydp_t^2}\right)\Big/\left(\frac{d^2\sigma_{pp}}{dydp_t^2}\right)$$

aka Cronin Effect

Inclusive pT Distribution of Negative Hadrons in the TPC



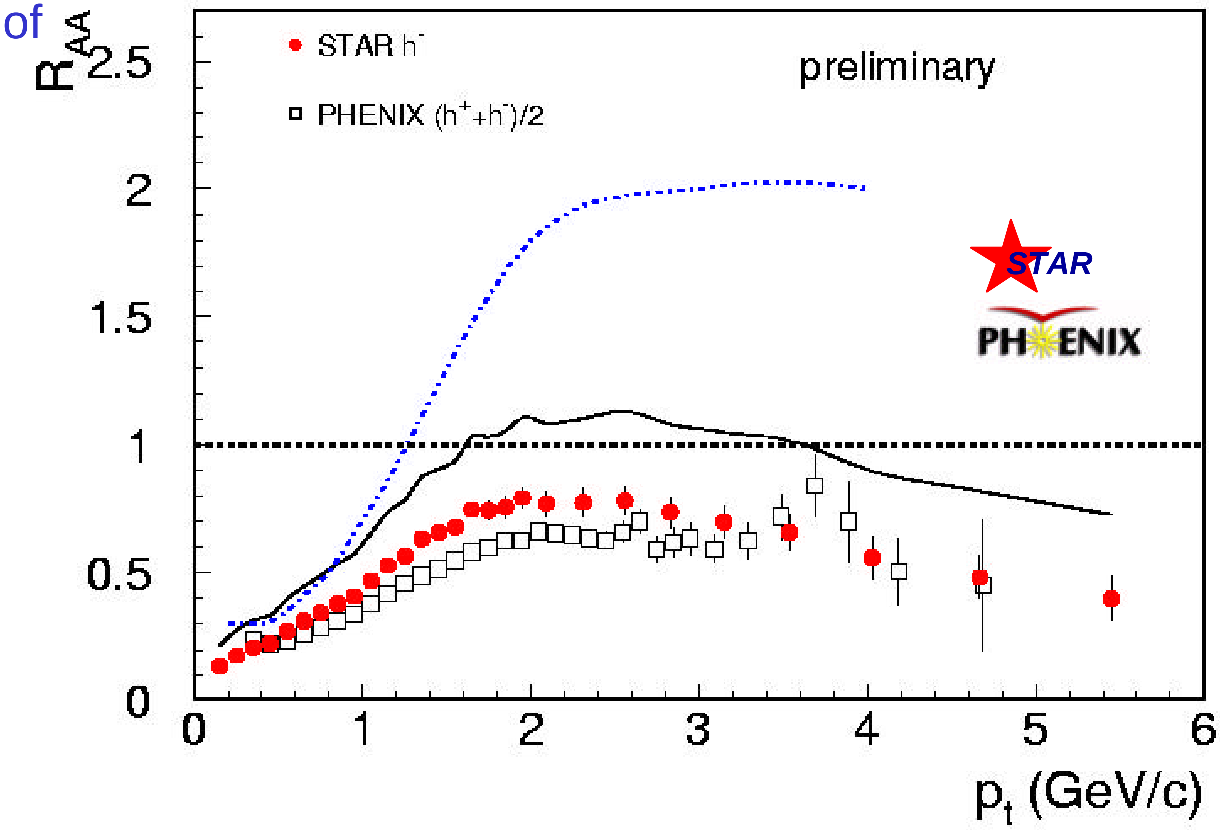


Hadron suppression relative to scaled NN of factor ~2

DATA: Comparison of Central Au-Au to p-p

- Use identical p-p parameterization for both data sets
- normalize data to number of binary collisions
- divide by pp-reference (130)/42 mb

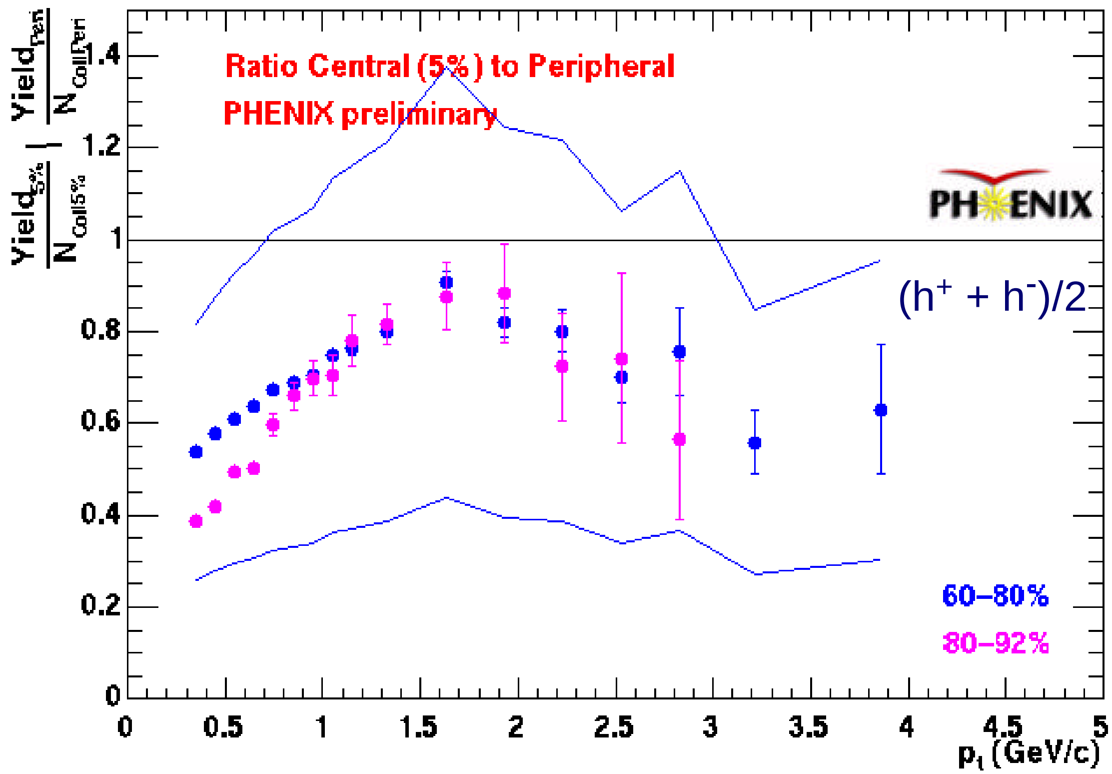
$$R = \frac{\mathrm{Au} + \mathrm{Au}}{\mathrm{pp}(130\,\mathrm{GeV})\ T_{AB}}$$



DATA: Comparison of Central to Peripheral Au-Au

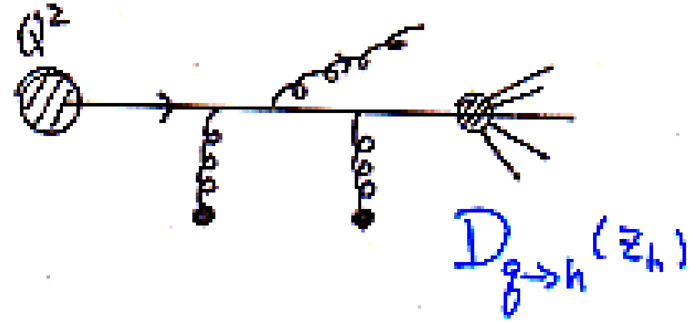
$$R = \frac{central / N_{bin}}{peripheral / N_{bin}}$$

- Normalize central and peripheral to number of binary collisions
- Different systematic errors:
  - many experimental errors cancel
  - systematic uncertainty ~60% on Nbin

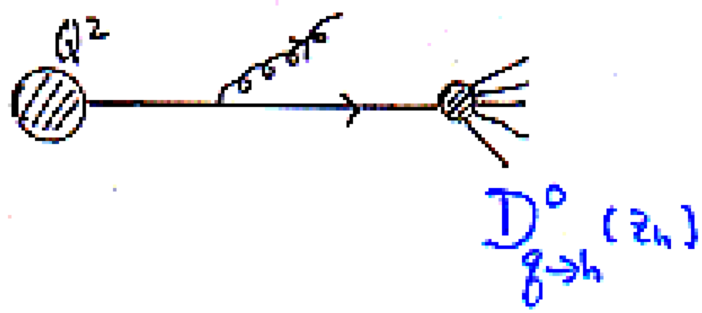


Suppression of 'Larger' Pt Spectra in AA

- Modified fragmentation function due to induced radiation

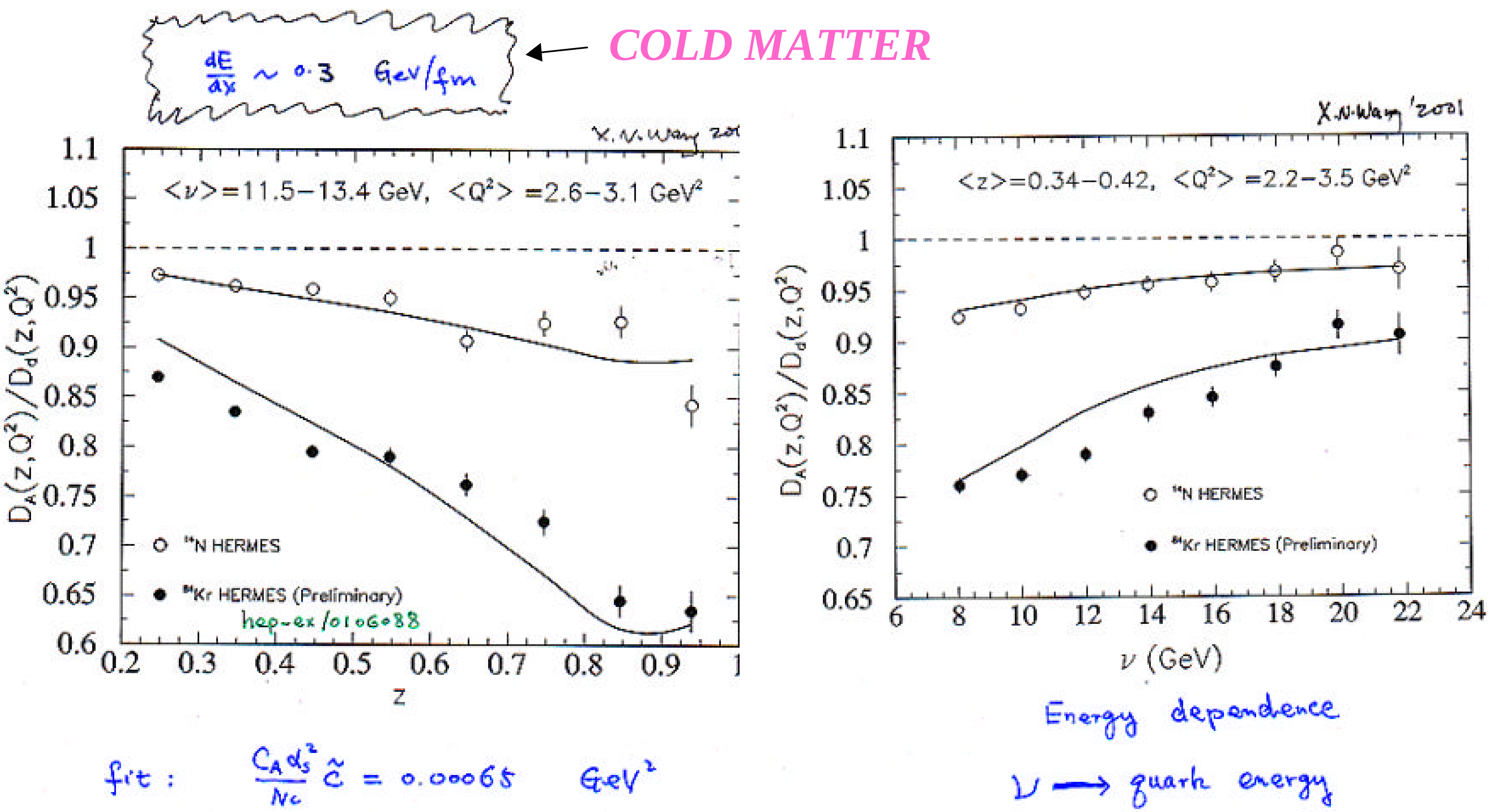


- Modified DGLAP evolution
  - Similar to radiation in vacuum but with medium effect



- Thermal absorption and Stimulated emission
  - Detailed Balance

Hadron Spectra at Hermes(eA) Ratio(A/d)



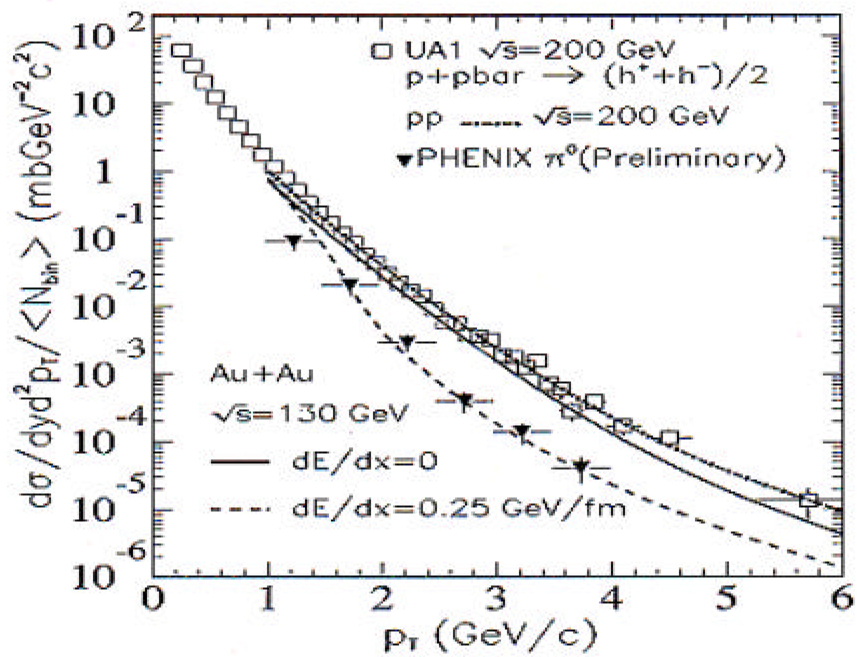
- Substantial reduction of hadron in positron-A collisions
- Energy loss and change of quark fragmentation function

Partonic Energy Loss or ‘Theorists are Fast’

- Wang and Gyulassi extract the mean partonic energy loss to be 1 GeV/fm
- :-(from Phenix data

$$\left\langle \frac{dE}{dx} \right\rangle \cong 0.25 \times \frac{1}{0.5} \times 2 \cong 1 \ \mathrm{GeV/fm}$$

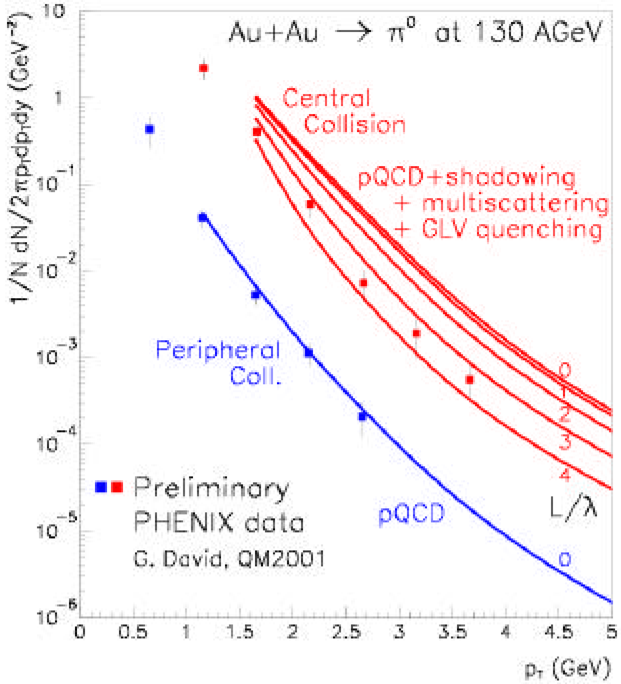
$$\frac{E^{static}}{E^{1D}} = 2$$

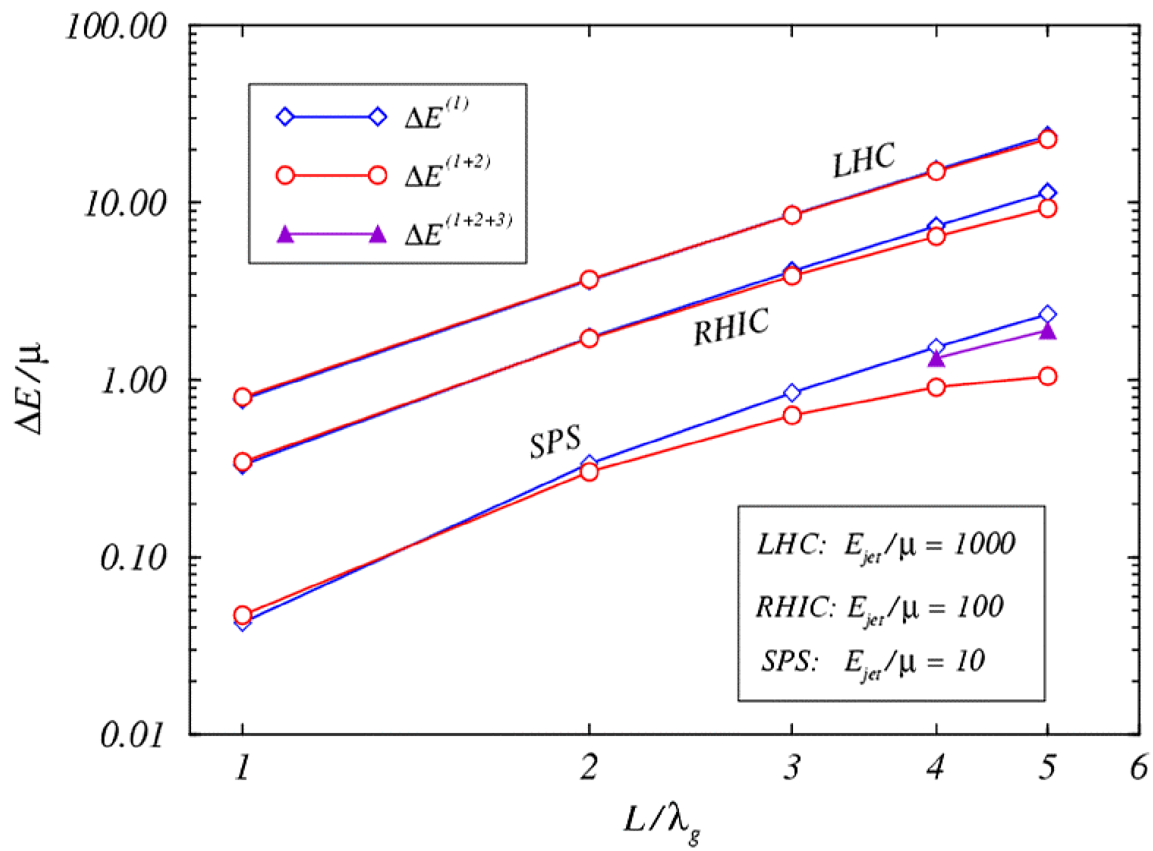


$$\Delta E \simeq \frac{9\pi C_R \alpha_s^3}{4} \int d\tau \, \rho(\tau) \, \tau \ln\frac{2E}{\tau\mu^2}$$

GVW '01

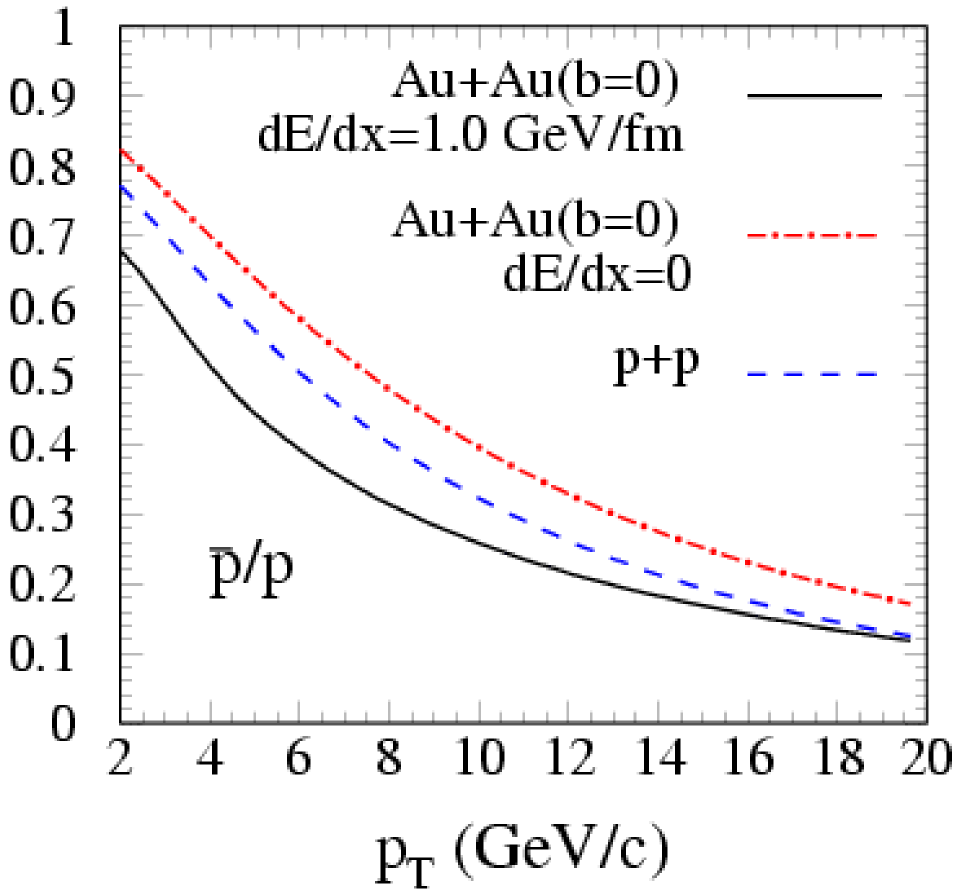
Partonic Energy Loss in Theory





- Vitev predictions
- RHIC Parameters
  - L ~ 5fm
  - mu ~ 0.4 GeV
  - Lambda ~ 1.6 fm
  - E ~ 10 GeV

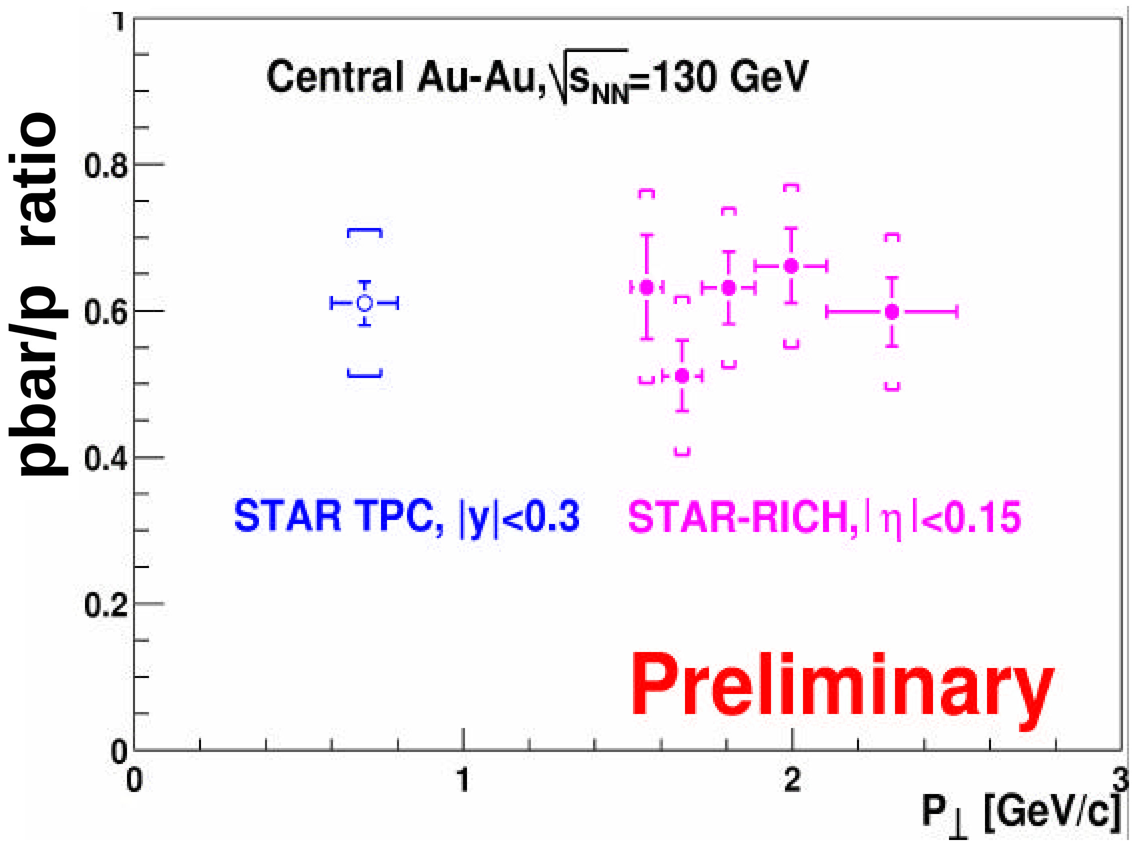
Energy Loss Sensitivity in Kaons,Lambda's and Protons



X.N.Wang, Phys.Rev.C **58** (1998) 2321

- Gluon fragmentation function is softer, therefore the ratio drops
- Antiprotons from g & q - jets
- Protons from q-jets
- Gluons couple stronger, therefore have a higher energy loss
- Ratio sensitive to partonic energy loss

pbar/p Ratio: What STAR has

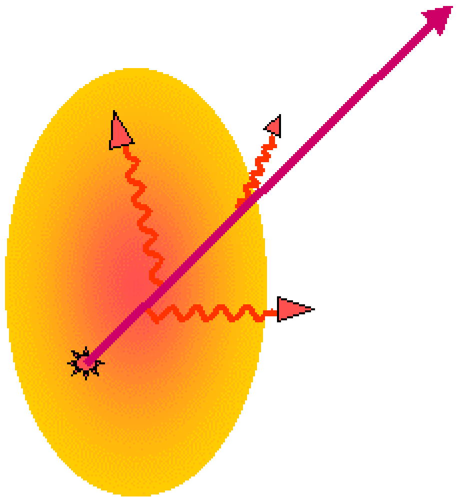


- Two Detectors
  - TPC
  - RICH
- Year one is TPC-calibration* and statistics limited (00hm)
- Not yet measuring into the highPt regime
- Quote: 'highPt is where the ratio starts falling'

* RICH had to change identification model from Templates to Cherenkov angle reconstruction

Gyulassy's Tomography

- Emphasis on having a calibrated probe to study the medium
- Especially the gluon density
- Look at anisotropy's
- V_2 and two particle correlations as the experimental tool

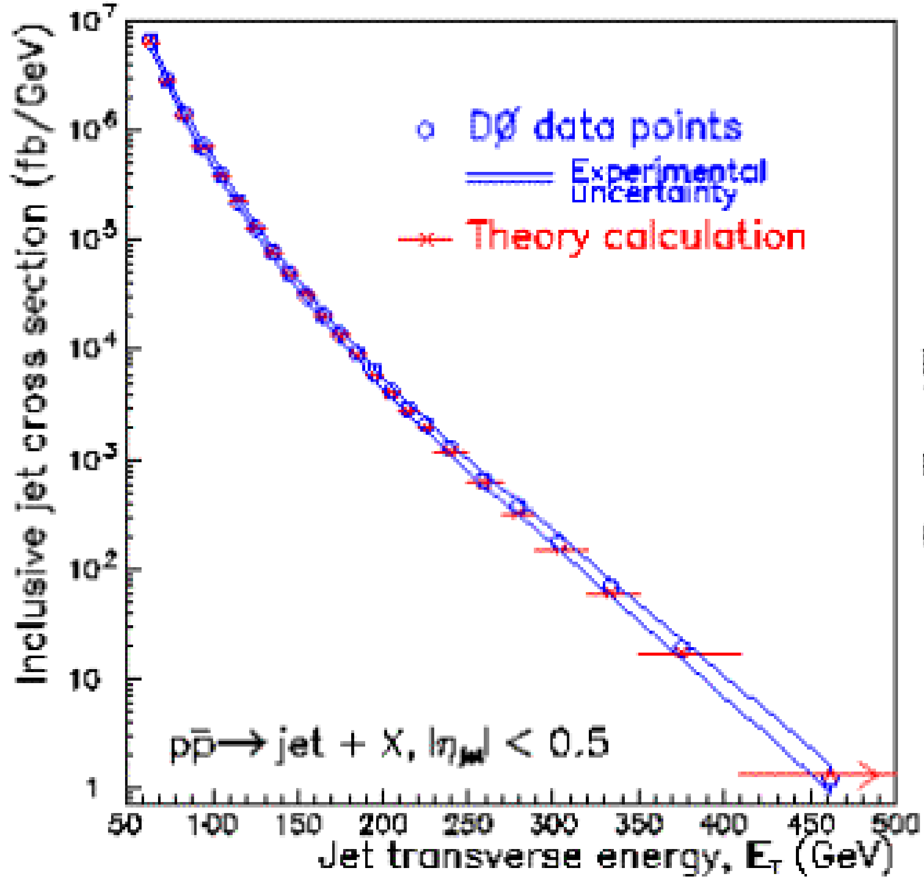


$$\Delta E_{GLV} \sim C_2 \alpha_s^3 \, \mathrm{Log}\left(\frac{E_0}{\mu^2 L}\right) \int d\tau \, \tau \rho_{glue}\left(\tau, r(\tau)\right)$$

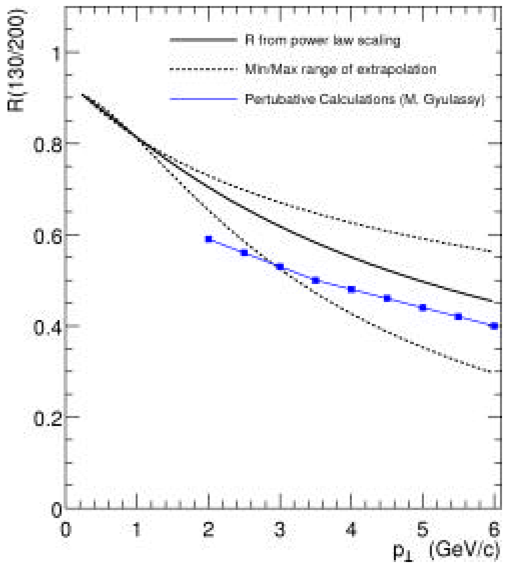
Gluon Density

Jet Calibration in pQCD

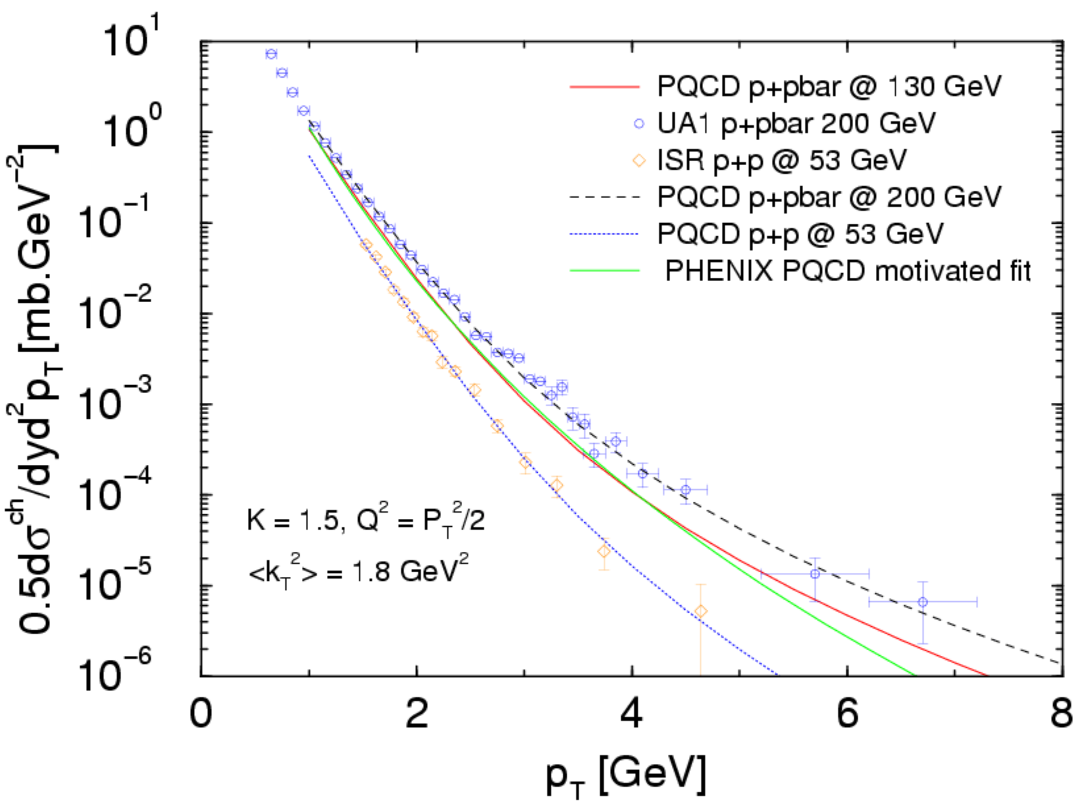
- How many jets are there in pp or
- How well calibrated are pQCD jets in pp Collisions ?
- Comparison shows theory is good to ~30% at best



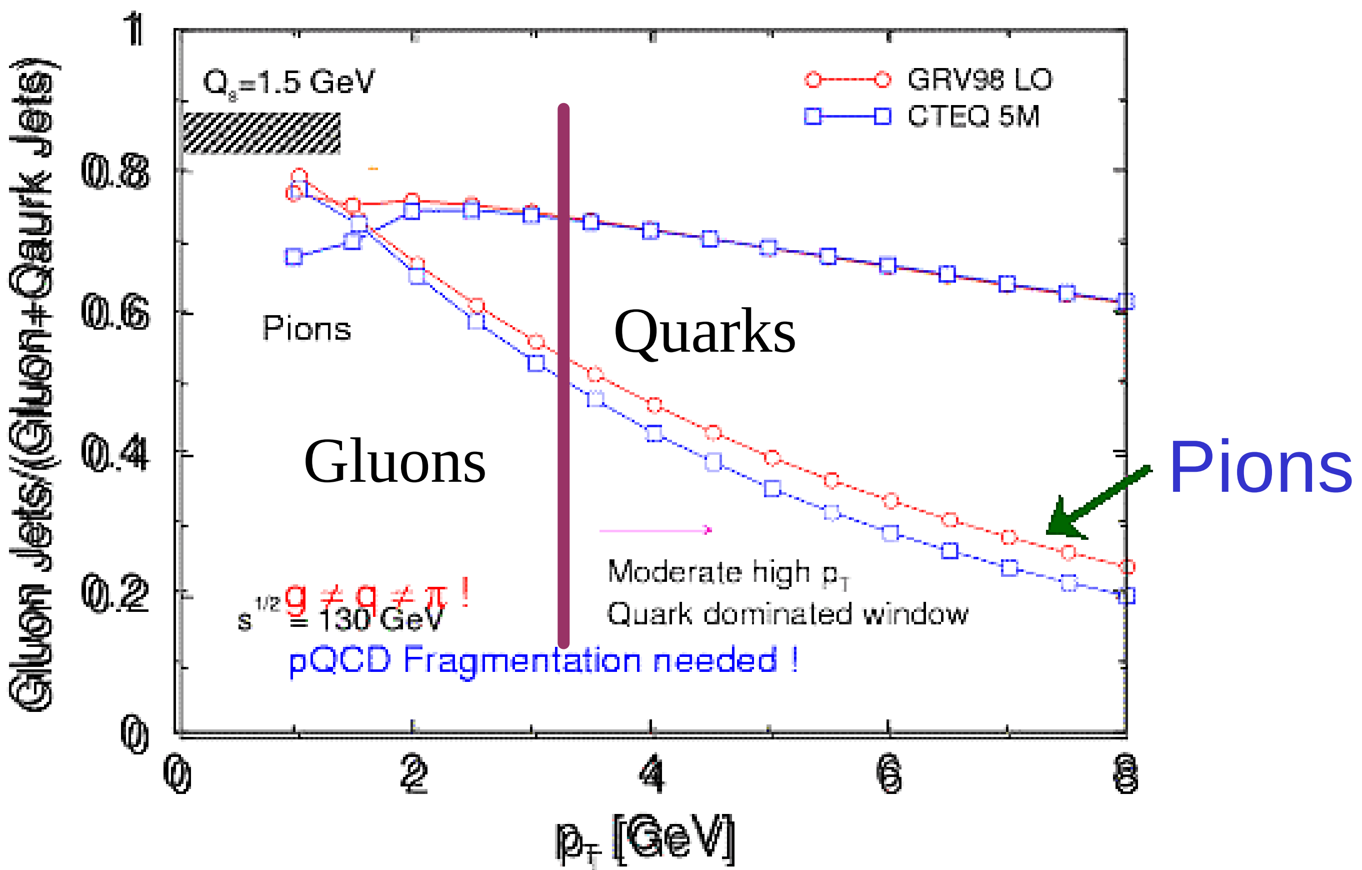
pQCD -> Hadrons



- How well is hadron production understood in pp ?
- Comparisons between 53,200 and 500 Gev are good to ~30 percent get better at higher Pt

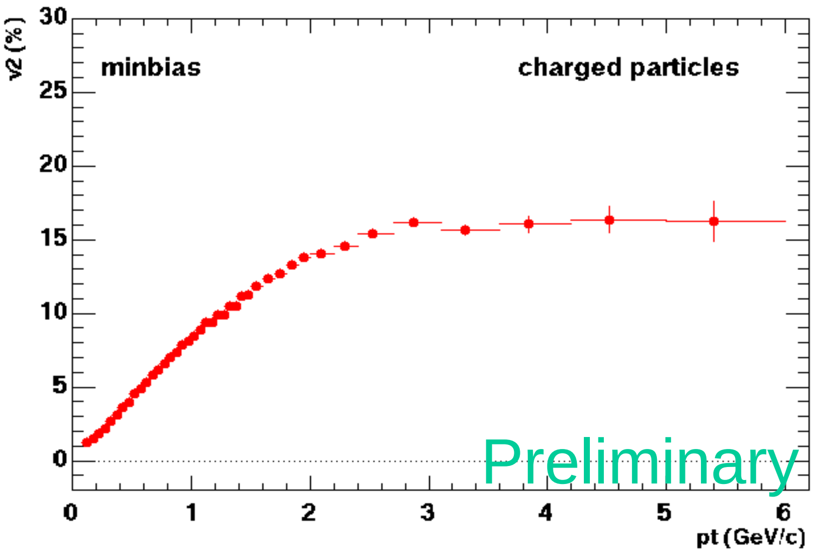


Are HighPt Probes from Glue or Quarks ?

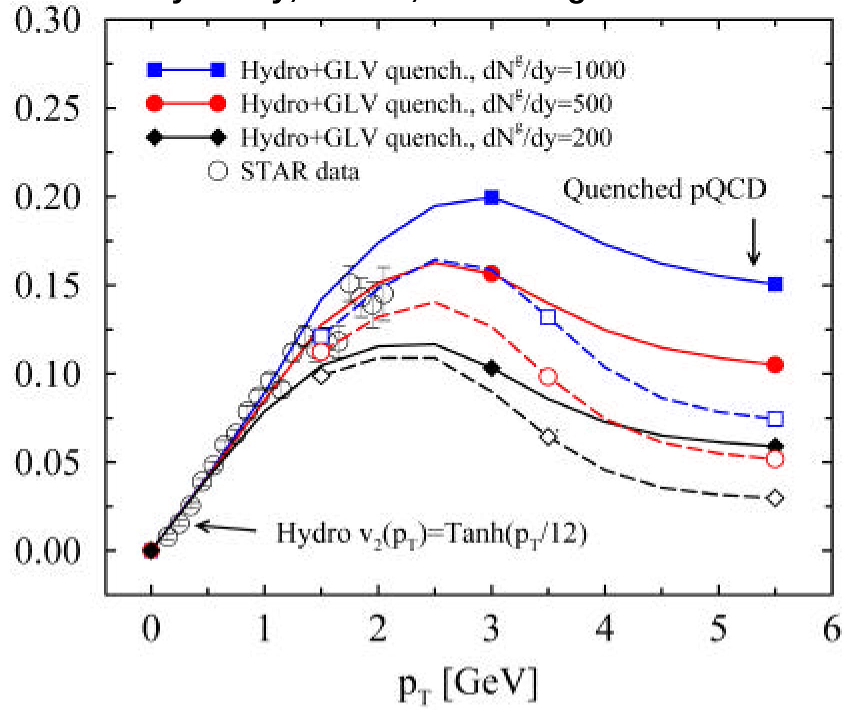


- What type jets are we looking at ?
- Depends on Pt ..... And the theory :-)

Correlations

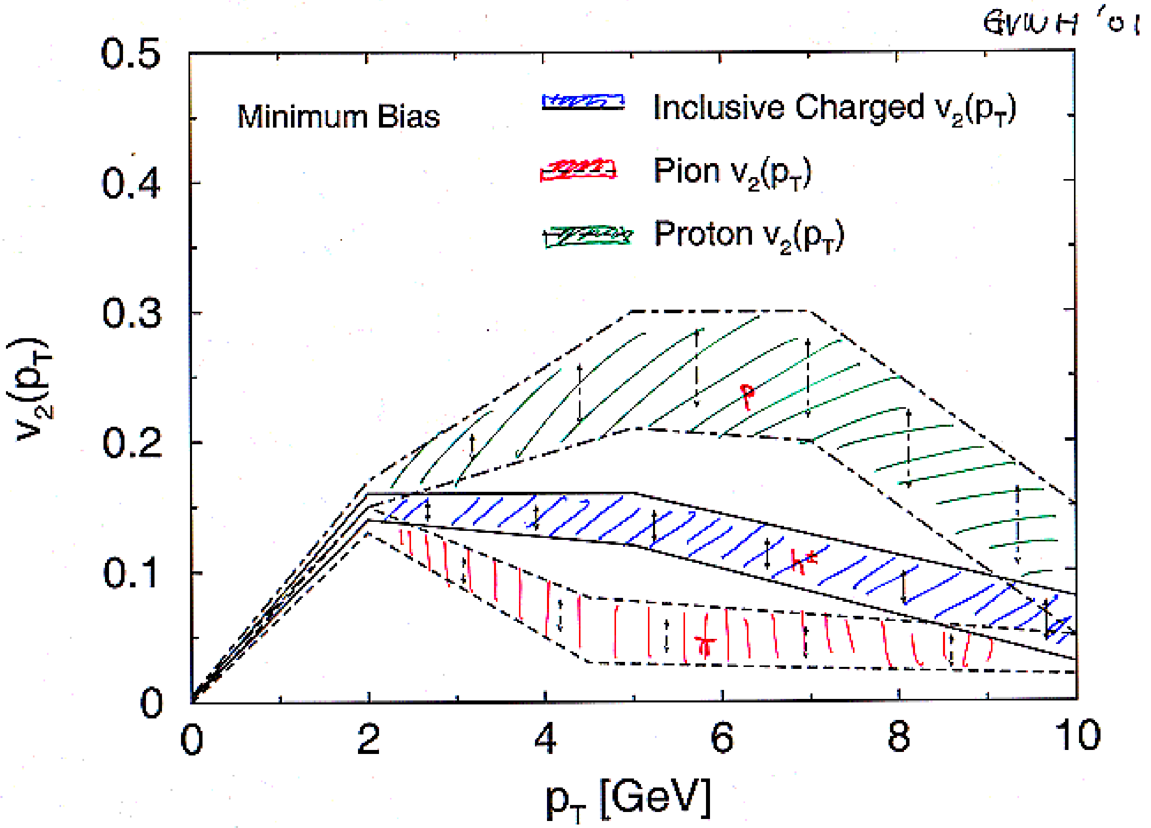


M. Gyulassy, I. Vitev, X.N. Wang nucl-th/0012092



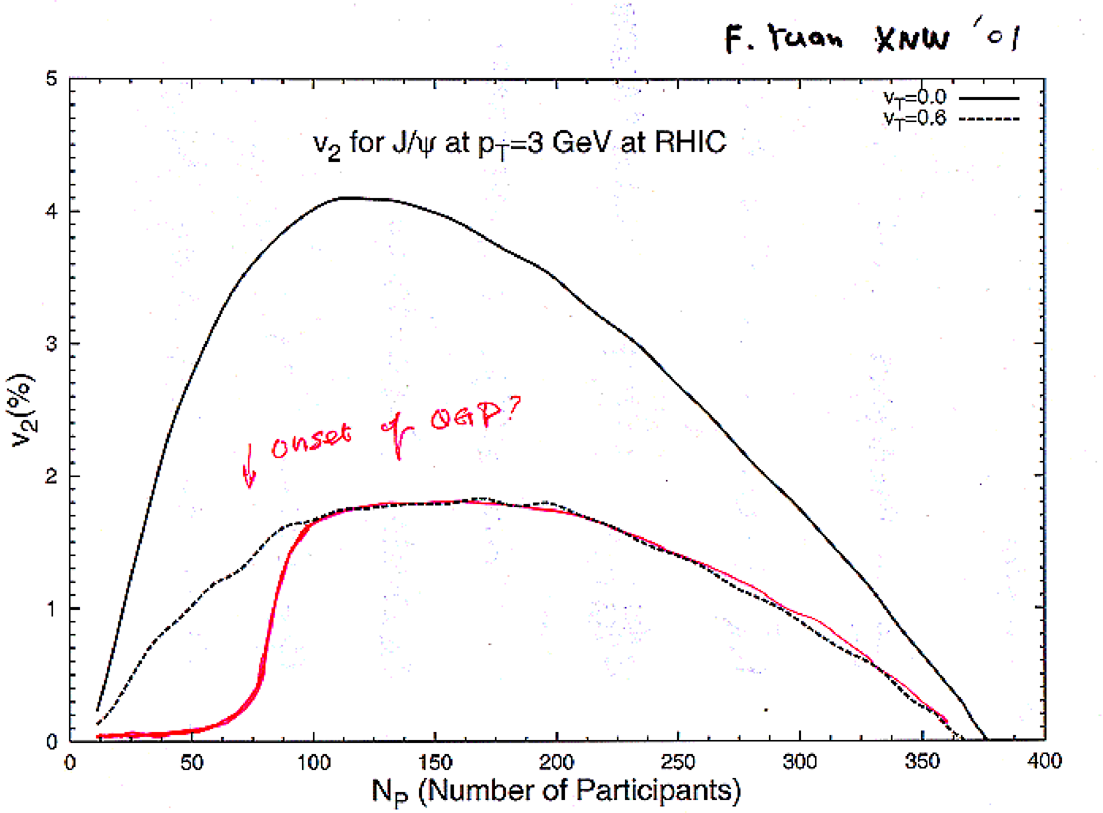
- Measurements by V2 and 2 and 4 particle correlations (V2 depends on a reaction plane determination by soft particles)

V_2 or 'A Very Interesting Prediction' !



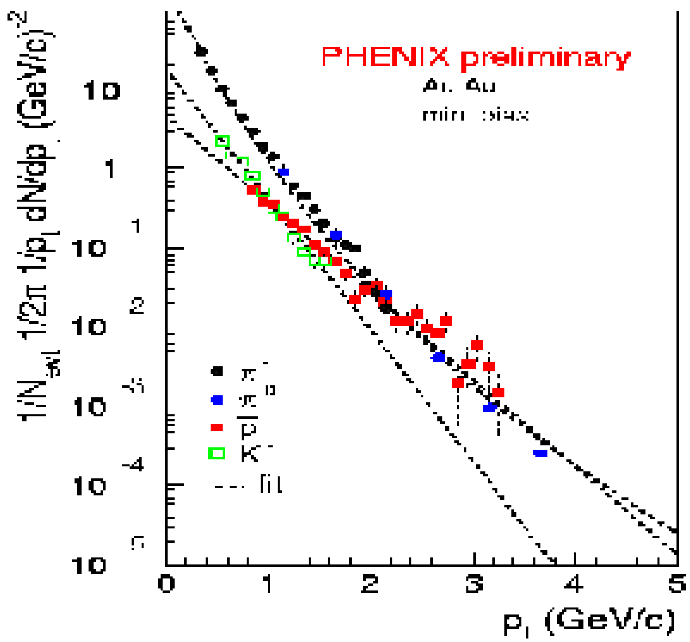
- Depends strongly on P_{trans} window
- Depends on species
- PID at high momentum

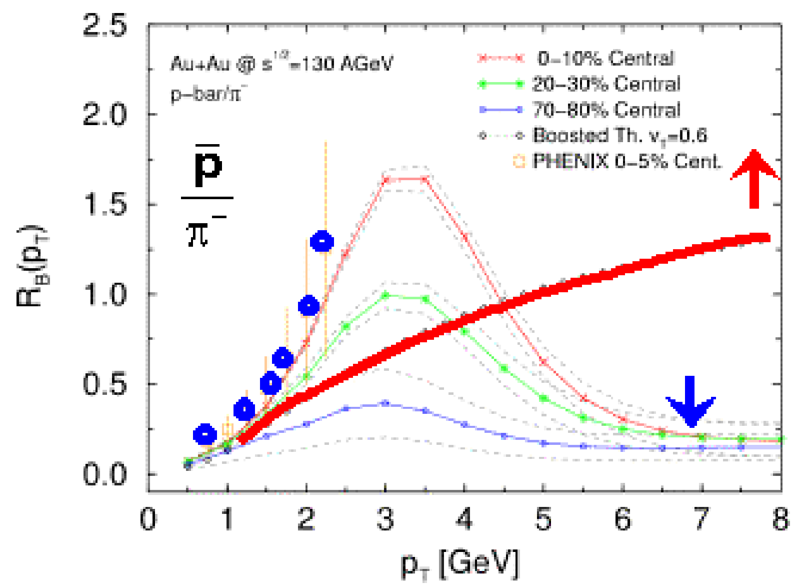
V_2 for the Jpsi !



- **STAR Future !**

New Physics : Baryon to Meson Ration

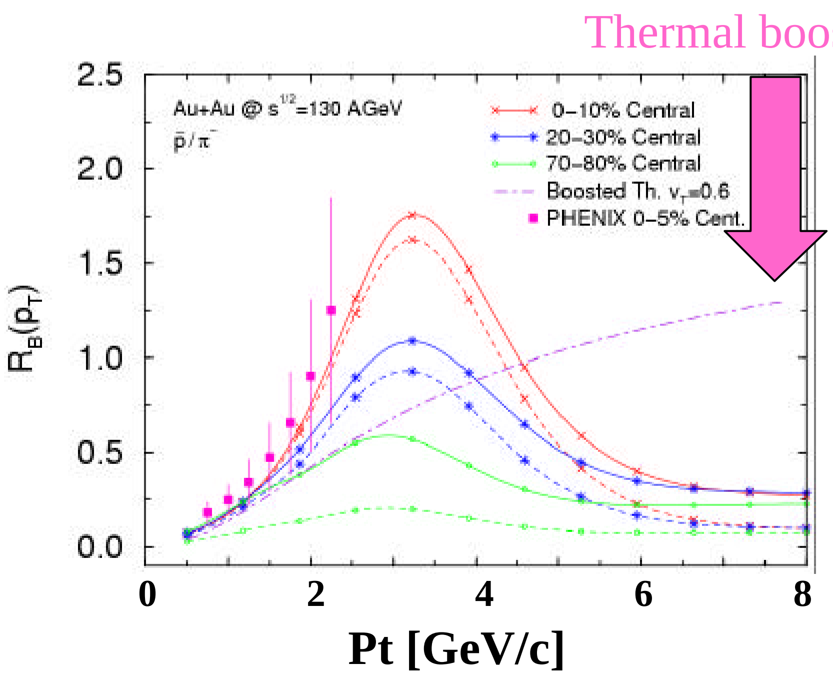


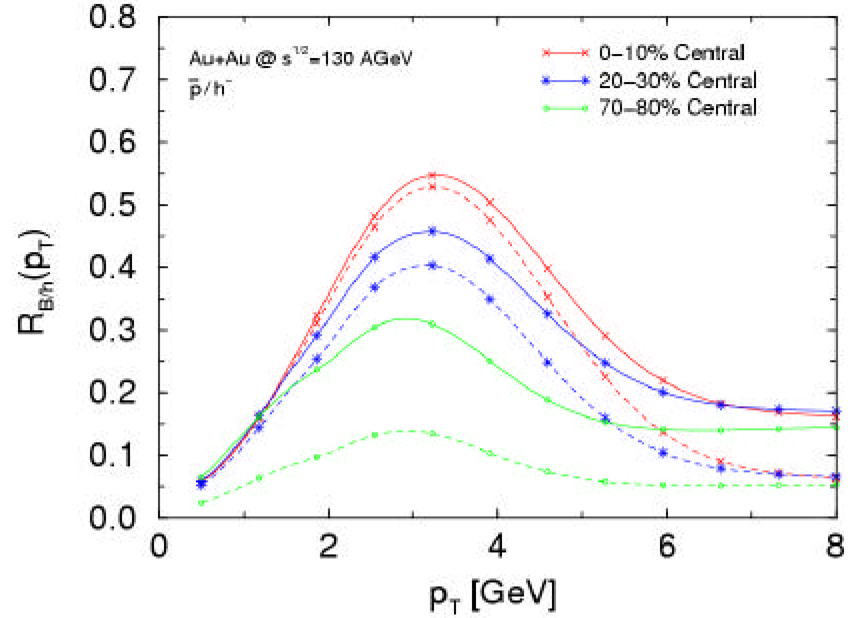


- **What PHENIX observes and we will be able to study soon soon (... calibration, calibration calibration .....)**

• More Anti-protons than Pions above 2 GeV/c

Anomalous Baryon Component Revealed by Jet quenching





- Boosted thermal source give monotonically growing ratios
- Need Baryon Junction Model to describe data (Vitev et al.)
- Prediction of a window in which effect is strongest !

Summary and Conclusion

- Exciting physics, needs pp and pA to be conclusive
- Will teach us about interactions in medium and connects to QCD
- Future (which I did not have time to elaborate on, but we know the EMC and EEMC are nearly in !) is bright ! Pi_0 physics and Charm and B physics, gluon structure functions in pp !
- Needed is a well calibrated and understood TPC to live up to the CDR projections of momentum range (we do not want to publish charge integrated papers with this beautiful detector !!)
- Concrete Proposal :
  - Build a task force with the charge to use the 2001 data to calibrate to TPC in a time for a Feb/March production (we learned a lot already and now have 5 different B settings so it is not just a dream !)
  - People on my personal Dream-Team : J.Dunlop, J.Thomas, B.Choi, D.Hardke, L. Barnby, G. v.Buren, C. Whitten and everybody who has a good idea !
  - Use X-rays for Calibration of the TPC !